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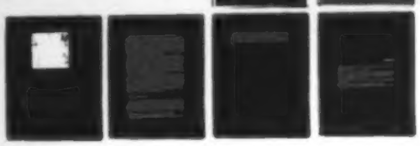

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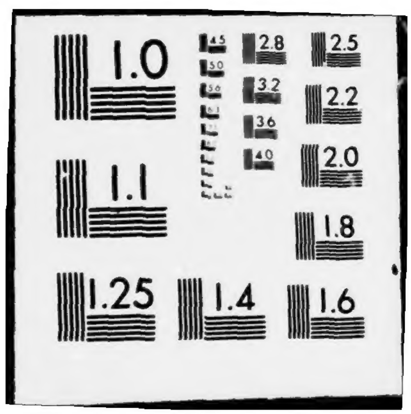
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LIGHTNING AND SQUALL LINE IDENTIFICATION FROM DMSP SATELLITE PHOTOGRAPHS

Air Force Geophysics Laboratory
Hanscom Air Force Base, Massachusetts

28 October 1976

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Lightning and Squall Line Identification From DMSP Satellite Photographs

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JAMES A. WHALEN

28 October 1976

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SPACE PHYSICS DIVISION PROJECT 7663
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HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

John Howard

Chief Scientist

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shows the satellite sensors' ability to detect squall lines during partially moonlit conditions.

Preface

The authors are grateful to George J. Gassman for his guidance and encouragement in this study, and to Jurgen Buchau for his role in the discovery of these lights. Major Wilson R. Edwards and Captain Richard Durham provided valuable assistance in obtaining synoptic charts and weather data. Contributions in reviewing the findings were made by several colleagues in the Ionospheric Dynamics Branch, Space Physics Division and in the Satellite Meteorology Branch, Meteorology Division.

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Lightning and Squall Line Identification From DMSP Satellite Photographs

1. INTRODUCTION

Nighttime lightning storms have been observed by photometers on OSO-2 and OSO-5 satellites.[1] In these observations, two photometers sensitive to broad spectral regions in astronomical blue (approximately 3500 to 5000 Å) and red (approximately 6000 to 8000 Å) were used for the detection of lightning. The photometers were protected from excessive light levels, which effectively limited the lightning observations to times near new moon and to satellite nadir. With the Defense Meteorological Satellite Program (DMSP) high resolution nighttime photographs, lightning has been identified during new moon and moonlit conditions and locations mapped over the 3000-km-wide field of view. This paper describes the signatures of lightning in the DMSP data and demonstrates the correctness of interpretation by comparison with ground observations.

In general, DMSP satellites are operated by the U.S. Air Force Air Weather Service. This organization routinely provides high resolution nighttime satellite photographs to the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Geophysical and Solar Terrestrial Data Center in Boulder, Colorado, for copying and for general

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(Received for publication 28 October 1976)

1. Sparrow, J.G., and Ney, E.P. (1971) Lightning observations by satellite, Nature, 232:540-541.

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distribution. The Data Center then sends the original photographs to the Air Force Geophysics Laboratory for analysis in auroral and ionospheric research.

The DMSP satellites are at an altitude of from 815 to 850 km and are in a 99-deg sun-synchronous orbit. The satellites are kept in noon-midnight and in dawn-dusk orbital planes. The photographs are produced in a line-scanning radiometer. With this line-scanning technique, the field of view of the detector is swept repetitively across the earth, perpendicular to the path of the satellite, and through the subsatellite point. The cross track scan is reproduced by a mirror rotating at 1.78 rev/sec or every 562 msec. During a rotation of the mirror the earth is viewed for 180 msec (A. L. Snyder, private communication[2]). The orbital period of the satellite is 102 min. Because of the oribtal motion of the spacecraft, adjacent scan lines along the track are separated by 3.7 km at the surface of the earth. The resulting photographs cover an area about 3000-km wide, in a general east-west direction. The spectral range of the detector is from 0.45 to 1.1μ, thereby covering both the visible and the near infrared portion of the spectrum.[3] The extension into the infrared tends to optimize the sensors' ability to distinguish among clouds, ground, and water.

Since the satellite photographs provide a unique means of seeing auroral forms in detail on a large scale, they have been used in auroral research and investigations of the arctic ionosphere by the Air Force Geophysics Laboratory. Analysis of these photographs, which view the aurora over a 3000-km width, substantiated the continuity of the auroral oval or the Feldstein auroral oval concept.[4] The ability of the photographs to portray detailed forms of the aurora further substantiated the auroral substorm concept of Akasofu and the various phases of these substorms on consecutive DMSP passes.[5]

2. ANALYSIS AND RESULTS

Figure 1 shows a Defense Meteorological Satellite Program (DMSP) high resolution nighttime photograph that was analyzed for possible identification of lightning. The photograph, which was recorded on 14 November 1972 between 0626 GMT and 0629 GMT in the absence of moonlight, shows city lights identifying geographic features of the Gulf of Mexico, the Florida peninsula, and eastern

2. Snyder, A. L. (1974) Private Communication.

3. Morse, F. A., Nelson, D. F., Rogers, E. H., and Savage, R. C. (1973) Low energy electrons and auroral forms (Abstract), EOS Trans. AGU, 54:404.

4. Pike, C. P., and Whalen, J. A. (1974) Satellite observations of auroral substorms, JGR, 97 No. 1:985-1000.

5. Pike, C. P. (1974) DAPP satellite observations of aurora, EOS Trans. AGU, 55:604-605.

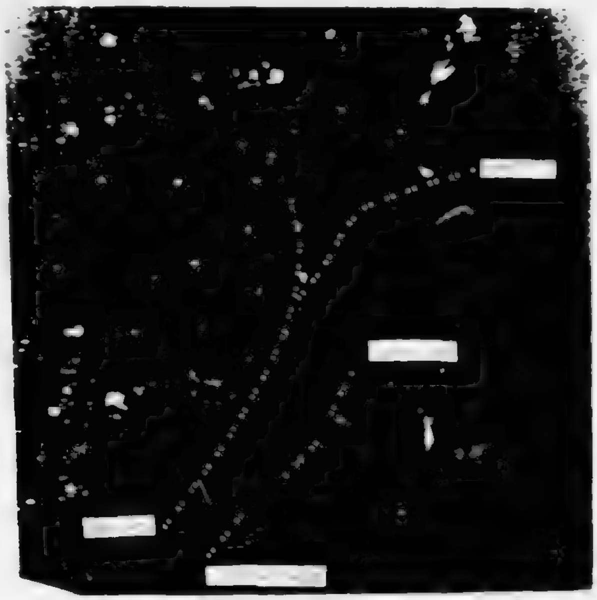

Figure 1. DMSP Satellite Photograph Recorded on 14 November 1972 Showing City Lights of the East and Midwest United States. Also shown are the superimposed positions of fronts and a squall line. Streaks in the warm sector are indicative of lightning. Numerous streaks over the Gulf of Mexico show squall line activity

seaboard regions (Figures 2 and 3 show maps of the area for comparison). Of particular interest, however, are a series of unusual light streaks over the Gulf of Mexico and similar, but more isolated, streaks over the eastern seaboard. The diffused city lights over the southeastern United States indicate cloud cover, hence suggesting that a definite weather regime is associated with the streaks. These streaks are interpreted as resulting from lightning activity associated with the cloud cover.

Since the satellite pass over the region of interest occurred near 0600 GMT, a synoptic chart for 0600 GMT (Figure 2) and a weather radar summary chart for 0540 GMT (Figure 3) were used to determine the mesoscalar weather pattern and the location of radar echoes near the time of the satellite pass. Selected weather station records indicating actual weather conditions during the satellite pass were also obtained. The 0300 GMT and 0900 GMT synoptic charts were used to obtain a time history of weather conditions and frontal movements.

The frontal positions analyzed on the 0600 GMT synoptic map (Figure 2) are those shown on the photograph (Figure 1). Savanah, Georgia, and Gainsville,

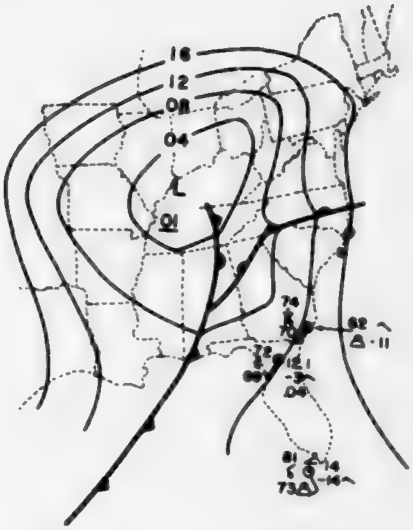

Figure 2. Synoptic Chart for 0600 GMT 14 November 1972 Showing Stations Reporting Lightning or Thunderstorm Activity. This drawing is based on the geography as seen on the DMSP photograph

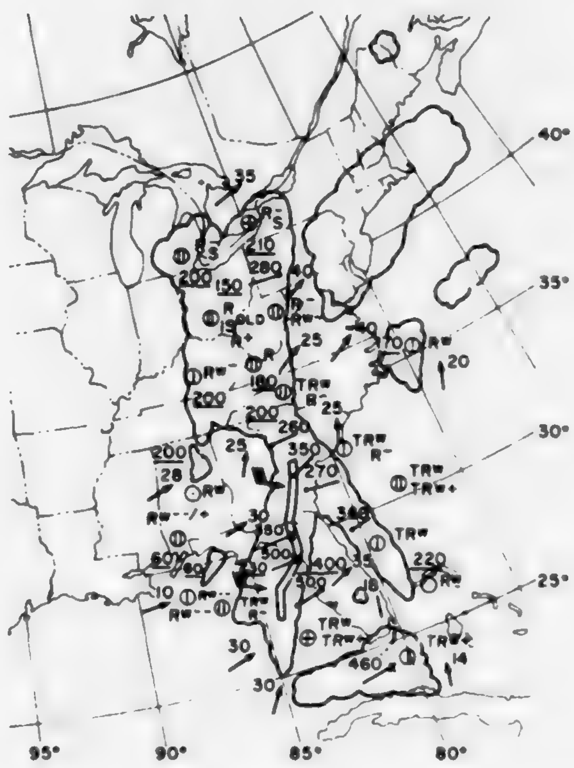

Figure 3. Radar Summary Chart for 0540 GMT 14 November 1972 Showing Radar Echoes in Area of Interest

Florida, and an extrapolated squall line over the western Florida peninsula and the Gulf of Mexico show streaks that are characterized as lightning. Individual surface weather records from the stations above confirmed the occurrence of lightning during the satellite pass. The Key West, Florida, weather station record indicated occasional lightning towards the southeast. Hence, lightning may not have been present during the satellite pass. The lightning streak located near the warm front could not be confirmed by thunderstorm activity on the synoptic chart. However, the radar summary report (Figure 3) shows thundershowers with cloud tops ranging from 26,000 to 20,000 ft at that location. The radar report further supports the northern portion of the squall line. The 0600 GMT synoptic chart shows thunderstorm and lightning being reported at Savannah, Georgia, Gainesville, Florida, and Key West, Florida (Figure 2).

Figures 4 and 5 are photographs that were recorded during partial moonlit conditions on two consecutive DMSP orbits on 23 May 1973. Figure 4, recorded between 0611 GMT on 0615 GMT, shows the East Coast, the Florida peninsula, and the Gulf Coast outlined by city lights. The angle of incidence of moonlight is such that cloud visibility is enhanced over the Atlantic Ocean, with diminishing enhancement toward the satellite track (center line of picture). Lightning streaks

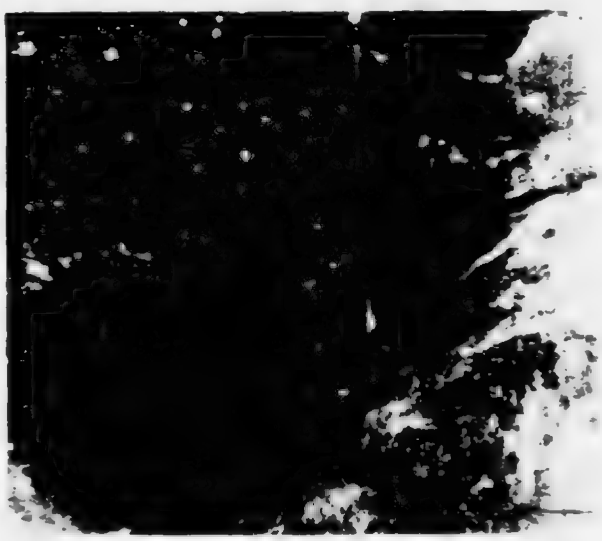

Figure 4. DMSP Satellite Photograph Recorded on 23 May 1973 During Partial Moonlit Conditions Showing Clouds. The photo shows the continental outline of the United States East Coast and Gulf Coast. Squall line activity can be identified by lightning streaks at top center of the photograph

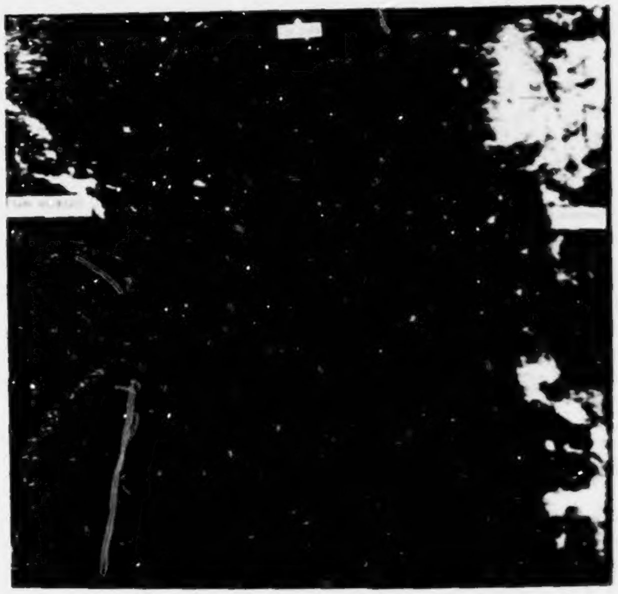

Figure 5. DMSP Satellite Photograph Recorded on the Next Orbit on [illegible]. Cities are identified for proper orientation. Lightning streaks indicating a squall line are seen in the cloud deck in the upper-right portion of the photograph

at the top of the photograph are indicative of squall line activity over Indiana, Kentucky, Tennessee, and Arkansas. The 0600 GMT synoptic chart confirmed the position of the squall line and verified the lightning streaks by stations reporting thunderstorm activity.

Figure 5, recorded on the next orbit between 07[illegible] GMT and 0757 GMT, shows the southwestern United States and northern Mexico. City lights of Los Angeles, Denver, and Houston are identified for proper orientation. As in the previous figure, the cloud layer can be more easily identified on the right of the photograph because of lunar illumination. Characteristic lightning streaks are seen in the upper portion of the photograph. The 0600 GMT and 0900 GMT synoptic charts were used to determine the 0800 GMT position of the squall line. Streaks on the photograph and the surface squall line position show excellent correlation.

3. DISCUSSION

Lightning strokes have a typical mean duration of 200 to 500 msec (Lakskhminarayan[6]). The ability of the DMSP sensor to detect strokes depends upon the temporal and spatial distribution of the strokes, the stroke duration and intensity, and cloud structure. As opposed to a constant light source such as city lights, lightning appears as a white streak or a white and black streak on the photographs. The black portion is attributed to a saturation of the sensor and appears on the right of the white streak because the sensor is scanning from left to right. When the stroke duration exceeds the scanner rotation time of 562 msec, lightning will appear on the next scan as a composite streak.

In a comparison of streak lengths, it was found that some streaks were elongated as long as 350 km. It appears that the length is related to the brightness of the stroke as viewed by the sensor, or that the illumination by clouds tends to saturate the sensor. In any event, these streaks in the photographs are considerably longer than the actual length of a lightning stroke, which, for intracloud lightning, may have a length of 16 km or more.[7] In addition, other light sources such as gas fires from oil well burn-off show several elongated streaks on consecutive scans. The composition of these streaks appear as one large bright spot several orders of magnitude larger than the actual source.

The ability of the sensor to detect lightning from individual thunderstorm cells appears promising. A preliminary thunderstorm analysis of synoptic maps with DMSP passes within 1 hr of map time revealed good correlation between thunderstorm or lightning reports and characteristic signatures on the DMSP photographs. In that study, a lightning streak appearing within 110 km of a station reporting a thunderstorm was considered a verification. Using these criteria, 69 stations showed 47 verifications. Conversely, only 7 cases of lightning streaks on the photographs could not be verified by station reports.

4. SUMMARY AND CONCLUSIONS

A total of 11 DMSP photographs showing characteristic squall line signatures similar to those encountered in Figures 1, 4, and 5 were analyzed for the occurrence of squall line activity over the United States. In all cases the squall line was verified by synoptic charts. The results of this study constitute convincing evidence that squall lines can be detected with the current generation of DMSP

6. Lakskhminarayan, K.N. (1962) J. Sci. Indust. Res., 21D:228.
7. Malan, D.J. (1963) Physics of Lightning, London, The English University Press, 176 pp.

satellites using high resolution nighttime photographs. Real-time or near-real-time identification of squall line activity over uninhabited regions and oceans has definite implications to those charged with the responsibility of issuing severe weather warnings. The ability of the sensor to detect individual thunderstorm cells or isolated thunderstorms appears promising and warrants further investigation.

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2. Snyder, A.L. (1974) Private Communication.
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